BYTHOTREPHES CEDERSTROEMI IN SOUTH-CENTRAL ONTARIO LAKES:

A REVIEW OF THE BIOLOGY OF THE EUROPEAN INVADER, AND FIRST RECORDS OF ITS OCCURENCE IN THE ZOOPLANKTON OF INLAND LAKES IN CANADA

MARCH 1992

Ontario
Environment
Environnement

ISBN 0-7729-9062-X

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Report Prepared For:

Limnology Section
Water Resources Branch
Ontario Ministry of the Environment

MARCH 1992

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PIBS 1877
log 91-2345-086

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ABSTRACT

This report documents the presence of the European invader, *Bythotrephes cederstroemi* (Cercopagidae, Onychopoda) in the plankton of eight lakes in the District of Muskoka in south-central Ontario - Lake Muskoka, Lake Joseph, Lake Rosseau, Fairy Lake, Mary Lake, Peninsula Lake, Lake Vernon and Go Home Lake. Because this is the first record of the species from inland lakes in Canada, the biology of *B. cederstroemi* is briefly reviewed, and potential implications of its invasion of Canadian Shield lakes are discussed.

92-05284/

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1. INTRODUCTION

Bythotrephes cederstroemi Schoedler (Cercopagidae, Onychopoda) is a large, planktonic, invertebrate predator that has recently invaded the Laurentian Great Lakes, almost certainly from Europe. In 1990, it was observed in three small inland lakes in northern Minnesota (Jeff Schuldt and Glen Merrick, University of Minnesota at Duluth, pers. comm.). It has not been observed in any other inland lakes in North America (Garton and Berg 1990, D. Berg, Ohio State University, G. Sprules, University of Toronto, J. Lehman, University of Michigan, and C. Kerfoot, Michigan Technical University, pers. comm.). We present the first evidence that *B. cederstroemi* has invaded inland lakes in Canada, reporting its occurrence in eight large, connected, recreational lakes in the District of Muskoka in south-central Ontario. Because of the unprecedented nature of these observations, we briefly review the biology of the species, and speculate on the implications of the invasion for zooplankton and fish communities of Shield lakes.

2. REVIEW OF B. CEDERSTROEMI BIOLOGY

2.1 Taxonomy

In 1857, Leydig (1860) described an unusual freshwater zooplankton, *Bythotrephes longimanus*, which he included in the Polyphemidae of the Cladocera. The animal was very large for a cladoceran, with a caudal process up to 1 cm long, about three times the length of the body (Figure 1). Lilljeborg (1901) subsequently distinguished two species in the genus - *B. longimanus* Leydig and *B. cederstroemi* Schoedler, the latter having an s-shaped kink with associated setation, in the caudal spine (Figure 1).

Mordukhai-Boltovskoi (1968) remains the definitive reference on the taxonomy of the Polyphemidae. He distinguished three families in the superfamily Onychopoda (recently elevated to ordinal status by Fryer, 1987 a,b). The first, the Polyphemidae *s. str.*, is represented by the one genus, *Polyphemus*, with its single common freshwater species, *P. pediculus*. The second family, the Podonidae, includes six marine species, and 9 or 10

additional species confined to the Caspian Sea (Mordukhai-Boltovskoi 1967). The last family, the Cercopagidae, includes 16 species, of which only two, *B. cederstroemi* and *B. longimanus*, live in fresh water. The remainder inhabit the Caspian Sea, and are apparently derived from *B. longimanus*. Illustrations of *Bythotrephes* can be found in Mordukhai-Boltovskoi (1968) and Berg and Garton (1988), and in Figure 1.

The existence of two species of *Bythotrephes* is now questionable. Zozulya and Mordukhai-Boltovskoi (1977) were the first to suggest that *B. cederstroemi* was simply a cyclomorphic variant of *B. longimanus*. Recent work supports their suggestion. Evans (1988) noted that the appearance of *B. cederstroemi* in Lake Michigan changed from a *longimanus*-type to a *cederstroemi*-type with growth. Berg and Garton (in prep.) compared the genetics of *B. cederstroemi* collected from Lake Erie with that of European populations of *B. cederstroemi* and *B. longimanus*. Their data strongly suggest that there is only a single species of *Bythotrephes* that exists in distinct morphotypes. In this report, we will refer to the North American populations as the single species, *B. cederstroemi*. In doing so, we recognize that more research is needed to determine the influence of temperature, predation, and allometric growth on the morphology of the two 'species' (Evans 1988), and on the apparently different appearance of animals emerging from resting vs. parthenogenic eggs (J. Lehman, University of Michigan, pers. comm.).

2.2 The North American Invasion

B. cederstroemi colonized each of the Great Lakes during the 1980's. It was apparently first observed in Lake Ontario in 1982 (Lean et al. unpublished data, in Johannsson et al. 1991). Then it was reported in zooplankton collections from southern Lake Huron in December, 1984 (Bur et al. 1986). In the autumn of 1985, *B. cederstroemi* was observed in fish stomachs and plankton hauls from Lake Erie (Bur et al. 1986). At the same time (September, 1985), it was formally reported in Lake Ontario, in the cooling water intake to the Somerset Coal Generating Station (Lange and Cap 1986). It was first reported in zooplankton samples from Lake Michigan in August and September of 1986 (Lehman 1987, Evans 1988). Cullis and Johnson (1988) reported that *B. cederstroemi* had colonized extensive portions of the

north shore of Lake Superior by 1987, as evidenced by its presence on anglers' fishing lines and gear, and in the stomachs of chinook (*Oncorhynchus tshawytscha*) and pink (*O. gorbuscha*) salmon. Finally, completing reports for the major basins of the Great Lakes, Jin and Sprules (1990) noted widespread occurrence of *B. cederstroemi* in Georgian Bay and in the north channel of Lake Huron in 1988.

The original method of entry of *B. cederstroemi* into the Great Lakes remains a matter of some speculation. Lange and Cap (1986) suggested an atmospheric route involving either the direct transport of resting eggs through the air, or indirect transport on the feet of migrating birds. Evans (1988) noted that many European lakes that support sport fisheries also support *B. cederstroemi* populations. She almost whimsically suggested that perhaps "*B. cederstroemi* resting eggs were transported to the Great Lakes in the mud adhering to the tackle or boots of a European seaman, and then released into these salmon-rich waters as the seaman passed some idle hours in fishing".

The fourth and most plausible hypothesis is transport in the ballast waters of ocean going freighters (Bur et al. 1986). Sprules et al. (1990) have given careful consideration to the date of the initial *B. cederstroemi* invasion of the Great Lakes assuming this is the correct hypothesis. Using a population growth model, they calculated the length of time required for *B. cederstroemi* to reach densities observed in the Great Lakes when they were first noticed by plankton ecologists, assuming a seed population of about 1000 individuals, published values of *Bythotrephes* generation times, and estimated rates of loss of individuals to fish predation. Using this model, Sprules and colleagues suggested that *B. cederstroemi* were introduced into the Great Lakes in the late 1970's or early 1980's.

Keilty (1988) lends credence to this date for the initial invasion. He observed caudal spines of *B. cederstroemi* in the bottom sediments of Lake Erie only at depths corresponding with sedimentation dates more recent than 1981 (Keilty 1988, Sprules et al. 1990). Sprules et al (1990) noted that the number of ships in ballast that entered the Great Lakes peaked in the late 1970s and early 1980's. Such ships each carry an average of 7,500 m^3 of ballast water.

Both species of *Bythotrephes* exist in the British Isles, in Scandinavia and in the rest of Europe north of northern Italy, and across the USSR and northern China (Lehman 1987). Century-old records from lakes in Sweden suggest that they are persistent members of the fauna in lakes where they occur (Pejler 1975). Therefore, there are many possible locations of the source *B. cederstroemi* population.

Sprules et al. (1990) suggest Lake Ladoga, near Leningrad, USSR, as the most likely source lake. They note that the River Neva flows from this lake through Leningrad and empties into the relatively dilute (5-8 ppt salt) seawater of the Gulf of Finland. Lake Ladoga contains only *B. cederstroemi* (not simply *B. longimanus* or both species), an unusual situation for northern European lakes, and many ships destined for Great Lakes ports take on ballast in Leningrad.

Berg and Garton (in prep) provide strong experimental support for this hypothesized source of colonizers. They compared the genetic structure of *B. cederstroemi* collected from Lake Erie with that of established populations in Europe. The populations from the Great Lakes more closely resembled Finnish than German or Swedish populations, supporting Sprules suggested site of origin for the invasion.

2.3 *B. cederstroemi* Demographics and Behaviour

The seasonality of *Bythotrephes* populations in Europe is typical of that of cladoceran zooplankton from north-temperate lakes. Individuals are generally present in the water column during the entire ice-free season, reaching maximum densities in the summer (De Bernardi and Giussani 1975). Resting eggs are produced in the late fall and over-winter in the lake sediments. Young animals emerge from the resting eggs in the spring and early summer (Herzig 1985).

The seasonality of *B. cederstroemi* was first studied in the Great Lakes in 1987, and it apparently exhibited a pattern different from that of European populations. Abundance was highest in the late fall, not in the summer (Berg and Garton 1988, Evans 1988, Lehman

1988, Makarewitz and Jones 1990). This led Berg and Garton (1988) to suggest that temperature limited population size. However, by 1988, a seasonality more typical of Europe, one of peak abundance in the summer, was reported from Lakes Erie and Michigan (Evans 1988, Lehman 1988, Garton et al. 1990). The unusual 1987 pattern may simply reflect a time lag after colonization before the colonizing populations reached sizes that plankton biologists could detect.

Like many other zooplankton, *B. cederstroemi* may migrate from deeper to shallower waters at night. For example, at a 100 m deep station in Lake Michigan, Lehman (1987) recorded maximum animal abundances in the cool, dim waters of the metalimnion (30 and 40 m) in mid-morning. At night, the animals moved up into the epilimnion. Such behaviour is a characteristic response of freshwater zooplankton to the presence of planktivorous fish (Gliwicz 1986)

2.4. Consequences of the *B. cederstroemi* Invasion of the Great Lakes

When they are abundant, pelagic macro-invertebrate predators such as larval *Chaoborus* (Dodson 1972, Yan et al. 1991), *Neomysis* (Edmondson 1979), and *Leptodora* (Herzig and Auer 1990) can regulate the abundances of their prey. However, at the moment, there is no conclusive evidence that *Bythotrephes* regulates the structure of plankton communities in European lakes. Apparently, the necessary research - a comparison of consumption rates of prey by *Bythotrephes* with production rates of those prey - has not been performed. De Bernardi and Giussani (1975) come the closest. They demonstrated that the abundance of *Daphnia* in Lago Maggiore in Italy was controlled by predation from *B. longimanus* and *Leptodora kindti* in 1973. However, *L. kindti* was four times more abundant than *B. longimanus*. The more abundant predator was most likely the principle regulator of the *Daphnia* population.

The impacts of *B. cederstroemi* on plankton assemblages of the Great Lakes are also a source of controversy. Lehman (1988) and Scavia et al. (1988) suggested that *B. cederstroemi* has reduced the densities of *Daphnia* in Lake Michigan. Makarewitz and

Bertram (1991) have made a similar suggestion for *Daphnia* in Lake Erie. However, Sprules et al. (1990) found no evidence of a decline in densities of *Daphnia* in their Lake Michigan data, a more extensive data set than that of Lehman. Sprules and colleagues also suggested that the reproductive rate of *Daphnia* exceeds the predation capacity of *B. cederstroemi* at realistic predator densities for Lake Michigan; hence, no impact should be expected unless there are large changes in *B. cederstroemi* densities. In response, Lehman (in press) examined 1985 to 1988 *Daphnia* data from Lake Michigan. He reported the disappearance of the small-bodied *D. retrocurva*, and shift to larger morphs of *D. pulicaria*, and no change in the abundance or size structure of the luxuriantly-helmeted *Daphnia galeata mendotae* in Lake Michigan, coincident with the occurrence of *B. cederstroemi.* Lehman maintained that predation by *B. cederstroemi*, is the most likely explanation for these changes in the abundance and size structure of daphnids in Lake Michigan.

Investigations such as these are still in their early stages. For this reason and because the pelagic food webs of the Great Lakes are undoubtedly still reacting to the presence of the invader, the full impacts of *B. cederstroemi* upon open water ecosystems of the Great Lakes will, undoubtedly, not be fully apparent or understood for some time.

3. OCCURRENCE OF B. CEDERSTROEMI IN MUSKOKA LAKES

3.1 Introduction

Fisheries Assessment Units of the Ontario Ministry of Natural Resources routinely collect zooplankton samples from their study lakes to aid in their assessment of the status of fisheries. We (WD and LM) first observed *B. cederstroemi* in zooplankton hauls from Lakes Muskoka, Rosseau and Joseph in the spring and summer of 1989. On July 7, 1990, a cottager from Mary Lake, upstream of Lake Muskoka, brought a bucket of water containing hundreds of *B. cederstroemi* to a meeting of her cottagers' association. She had filled the bucket from the end of her dock on the south shore of the lake. Bernie Neary of the Ontario Ministry of the Environment was a speaker at the meeting and recognized the significance of the find. This prompted us (NY and TP) to conduct a reconnaissance of nine

other large lakes in the Moon/Go Home River watershed in the summer of 1990, and in the spring of 1991.

The objective of this section of the report is to document the occurrence of *B. cederstroemi* in the largest lakes in the Moon/Go Home River watershed in the District of Muskoka in south-central Ontario. The lakes are: Lake Muskoka, Lake Rosseau, Lake Joseph, Mary Lake, Fairy Lake, Peninsula Lake, Lake Vernon and Go Home Lake.

3.2 Description of the Study Lakes

The thirteen study lakes include all of the larger lakes located in the Moon/Go Home River Watershed, tertiary watershed number 2EB (Cox 1978), that empties into the east side of Georgian Bay through both the Moon and the Go Home Rivers south of Parry Sound. There are 2022 lakes larger than 1 ha in this 574,000 ha watershed. Their mean size is 37 ha (Cox 1978).

Aquatic Habitat Inventory Surveys (AHIS, Dodge et al. 1985) have been conducted for 381 (19%) of the lakes in the watershed (Ontario Ministry of Natural Resources - OMNR, unpublished data). The mean size of the surveyed lakes is 174 ha, reflecting a bias toward larger lakes which contain sport fish species of interest to OMNR fisheries managers.

Sixty-nine species of fish have been recorded in the watershed, the most common being the white sucker (*Catostomus commersoni*), which has been found in 67% of the surveyed lakes. Ranged in order of decreasing frequency of occurrence, the next most common species are yellow perch (*Perca flavescens* - 62% of surveyed lakes), pumpkinseed (*Lepomis gibbosus* - 54%), smallmouth bass (31%), brown bullhead (*Ictalurus nebulosus* - 38%), creek chub (*Semotilus atromaculatus* - 31%), and brook trout (*Salvelinus fontinalis* - 31% of surveyed lakes). The major fish species recorded for our thirteen study lakes are listed in Table 1.

The location of the study lakes is indicated in Figure 2. Selected morphometric and water quality data for the lakes are provided in Tables 2 and 3, respectively. Excluding Bear Lake,

which some would consider to be a bay of Kawagama Lake, all the lakes are large (>600 ha). They are circum-neutral in reaction, suffering little from the impacts of acid precipitation (Table 3). The lakes are generally oligotrophic, having TP (total phosphorus) levels of 1-11 mg/m^3, and nitrogen/phosphorus ratios >30 by weight. The latter indicates that phytoplankton yields in the lakes are limited by available phosphorus. Transparency varies widely among the lakes (Table 3) and is more strongly and negatively correlated with concentrations of dissolved organic carbon ($r = -0.94$, $P<0.001$), than with TP ($r = -0.76$). This is a common observation for Shield lakes (Dillon et al. 1986).

3.3 Methods

Two different sampling methods were employed routinely in this study. Zooplankton were collected (by WD and LM) from Lakes Joseph, Muskoka, and Rosseau on roughly a monthly schedule during the ice-free seasons of 1989 and 1990. In 1989, samples were collected from 9, 9 and 7 stations, respectively, in the lakes. In 1990, to provide better coverage of open waters, two stations (4 and 8) were added to the Lake Joseph programme, and three stations (6, 11 and 12) were added to the Lake Rosseau programme. Stations 5, 10 and 11 were added to the Lake Muskoka programme, and station 14 was dropped (Tables 4-6, Figures 6 and 9).

At each station, triplicate vertical hauls from 0.5 m above the sediments to the lake surface were taken with either an 11.5 cm or a 13 cm diameter, conical tow net constructed of 76 μm. The contents of the three hauls were pooled into a composite for enumeration. Sample volumes were calculated assuming 100% filtration efficiency, a reasonable assumption given a 13:1 filtering area:mouth area ratio.

Zooplankton were collected from the remaining lakes (by TP) in vertical hauls with a 46 cm diameter, conical tow net constructed of 150 μm mesh (Yan et al. 1985). Hauls were taken through 30 m at stations >30 m, and from 2 m above the bottom at shallower stations (Table 7). Occasionally, zooplankton were also collected in horizontal hauls using either the 46 cm diameter net, or a 47.5 cm diameter closing tow net constructed of 500 μm mesh.

Samples were collected at several stations in each lake (Figures 3, 4, 5, 7, 8, 10, 11, 12, and 13) in July and August of 1990 and/or in June of 1991 (Table 7). The nets were equipped with a Rigosha flow meter, and towed at a velocity exceeding its stall speed when mounted in this net. Filtration efficiencies used to estimate sample volumes averaged 59.8%.

Some historical samples were available from Lake Muskoka, Lake Rosseau and Lake Joseph. B. Hutchinson (Ontario Ministry of the Environment, Dorset Research Centre) collected these samples as metered vertical net hauls from 14 stations in Lake Rosseau on July 27, 1983, 15 stations from Lake Muskoka on July 31, 1984, and from 12 stations in Lake Joseph on August 8, 1984. Unfortunately, no historical samples are available from the other study lakes, to our knowledge.

All samples were preserved in the field with either a 4 or 5% sucrose formalin solution. They were subsequently examined in their entirety for *B. cederstroemi.*

3.4 Results

Bythotrephes was not detected in any of the samples collected from Lakes Muskoka, Rosseau and Joseph in 1983 and 1984. This is not surprising as the invader was not recorded in North America prior to 1982 (Johannsson et al. 1991). In 1989 and 1990, *B. cederstroemi* was present in each of these three lakes. It was encountered at four of the stations in Lake Joseph (Table 4), and at seven of the stations in Lake Rosseau (Table 6). In 1990, *B. cederstroemi* was encountered in all of the monthly sampling runs for lake Rosseau. Of the three lakes, *B. cederstroemi* was most commonly encountered in Lake Muskoka. In 1989, for example, it was found at at least one station in all five sampling runs. Further it was encountered at all but one of the stations, including the shallowest and the deepest stations sampled (Table 5).

B. cederstroemi was recorded in the 1990 collections from Fairy and Mary Lakes (Table 7), but it was not observed in that year in Lake Vernon and Peninsula Lake, which are connected with Fairy Lake by broad, flat-water channels. However, in the spring of 1991

B. cederstroemi was collected in surface horizontal hauls from both Peninsula Lake and Lake Vernon (Table 8). In 1991 we also encountered *B. cederstroemi* at one of six stations in Go Home Lake, downstream of Lake Muskoka (Table 7).

In summary, the presence of *B. cederstroemi* is confirmed in Go Home Lake, Lake Muskoka, Lake Rosseau, Lake Joseph, Mary Lake, Fairy Lake, Peninsula Lake and Lake Vernon. *B. cederstroemi* was not collected in Skeleton Lake, Three Mile Lake, Lake of Bays or Kawagama Lake. Either it is not present in these lakes at this time, or it is present at densities below detection limits which can be approximated from the summed sample volumes to be 0.2, 0.67, 0.053, or 0.08 animals m^{-3}, respectively (Table 7).

3.5 Discussion

3.5.1 Source and Timing of the Muskoka Lakes Invasion

B. cederstroemi has been observed in only one other set of inland lakes in North America. Jeff Schuldt and Glen Merrick (University of Minnesota at Duluth, pers. comm.) collected *B. cederstroemi* in plankton hauls in Fish Lake, Boulder Lake, and Island Lake, three lakes in the Cloquete River watershed in northern Minnesota, U.S.A., in September, 1990. They suspected that *B. cederstroemi* had been introduced into these lakes by anglers.

Anglers may also have introduced *B. cederstroemi* into the Muskoka Lakes. The lakes support important summer and winter recreational fisheries for lake trout, smallmouth bass and walleye, for example, 20,000 to 40,000 angler-hours/yr of effort on lakes Rosseau and Joseph (Ontario Ministry of Natural Resources, unpublished data). We asked operators of marinas on Lake of Bays, Lake Muskoka, Lake Rosseau, Lake Joseph, and Fairy Lake if boats are moved from the Great Lakes into their lakes. They confirmed that such movement does occasionally occur. *B. cederstroemi* could have been introduced into the inland lakes by anglers or other boaters in various ways, the most obvious being spillage of Great Lakes water containing *B. cederstroemi* from live wells of fishing boats, or from anglers' bait buckets. Anglers are also suspected of accidentally or intentionally introducing

northern pike (*Esox lucius*), margined madtom (*Notorus insignis*), and black crappie (*Pomoxis nigromaculatus*) into various lakes in the watershed.

The marina operators also indicated that boats are frequently moved among our study lakes. This should speed the dispersal of *B. cederstroemi* within the watershed, now that it is established.

Of course we can not be certain how *B. cederstroemi* invaded the Muskoka lakes. The lakes are all isolated from Georgian Bay by several waterfalls and rapids; hence, colonizers could not have entered the lakes directly. In addition to recreational boaters or anglers, waterfowl may have served as the vector of colonization. It would be a short flight for migrating waterfowl from Georgian Bay to any of the colonized lakes (Figure 2). Jin and Sprules (1990) did report *B. cederstroemi* at all seven stations they visited in Georgian Bay in 1988.

While our intent was simply to report the presence of *B. cederstroemi* in Muskoka lakes, the design of future studies of its biology may benefit from this report, despite the sparseness of its data. In particular, three points concerning the daytime distribution of *B. cederstroemi* in the lakes are noteworthy. Animals were encountered at both shallow and deep stations in Fairy Lake and Lake Muskoka (Tables 5 and 7). They were readily collected in horizontal hauls just below the lake surface (Table 8). Finally, abundances in the epilimnion (0-6 m) of Fairy Lake exceeded those of the hypolimnion (7-17 m) on June 6, 1991 (9.5 vs. 1.1 animals m^{-3}, respectively, in closing net haul collections at Station 1 at 1300 hours). This last observation is apparently at variance with the vertical distribution of *B. cederstroemi* recorded from Lake Michigan (Lehman 1987).

From the available data we can not determine when *B. cederstroemi* invaded any of the study lakes, nor can we determine the sequence with which the colonized lakes were invaded. We know only that it was not observed in the 1983 and 1984 collections, nor indeed in earlier collections (Michalski et al. 1973), from Lakes Muskoka, Rosseau and Joseph. Our purpose

is simply to document the abundances of *B. cederstroemi* at an early stage of its colonization of the large lakes in the Moon River/Go Home River watershed.

3.5.2. Speculations on the Impact of *B. cederstroemi* on Canadian Shield Lakes

In theory, the magnitude of the impact of *B. cederstroemi* on Shield lakes should be a function of four factors - the number of lakes with suitable habitat, the dispersal rate of the invader, its average abundance and turnover time at steady state in lakes it colonizes, and its dietary preferences. We will consider each of these in turn.

In Scandinavia, *Bythotrephes*, mainly *B. longimanus*, is found in large and small lakes, deep and shallow lakes, acid and alkaline lakes, coloured and clear water lakes, and in lakes that are both rich and poor in nutrients (Hobæk and Raddum 1980, Næsje et al. 1987). It is not excluded from lakes that support fish populations, despite the fact that most fish species consume it. In fact, it is more commonly found in lakes with fish than in those without fish (Nilsson and Pejler 1973). Therefore, it is safe to assume that the majority of Canadian Shield Lakes provide suitable habitat for *B. cederstroemi*.

The colonization of Canadian Shield lakes by *B. cederstroemi* will probably not be limited by its dispersal abilities. Unfortunately, there has been little quantitative research on the dispersal rates of Cladocera. Daphnids, with their buoyant ephippia, apparently disperse rapidly, as evidenced by their rapid colonization of new habitats (Fryer 1985, Hebert and Hann 1986). The Onychopoda, including *Bythotrephes*, do not deposit their resting eggs in ephippia. Nonetheless, the presence of *B. longimanus* in previously glaciated, high elevation lakes in Scandinavia (Hobæk and Raddum 1980), and of *Polyphemus pediculus* in the high Canadian Arctic (Hebert and Hann 1986), indicate that the lack of an ephippium does not prevent the dispersal of onychopodids. In fact, the occurrence of *Bythotrephes* across so much of glaciated Europe and Asia suggests that dispersal rates of the genus are relatively rapid. Therefore, it seems reasonable to suggest that the ultimate distribution of *B. cederstroemi* in Canadian Shield lakes, in south-central Ontario at least, will not be limited

by their dispersal capabilities. Naturally the movement of people and boats among so many recreational lakes in south-central Ontario will speed the dispersal of the species.

Following colonization, the steady state abundance of *B. cederstroemi* in Canadian Shield lakes will probably be regulated by planktivorous fish. The body of *B. cederstroemi* is several millimetres long. It has a very large, darkly pigmented eye, and it is a relatively slow swimmer. In other words, it is a perfect target for planktivorous fish. In North America, *B. cederstroemi* have now been recorded in the stomachs of yellow perch (*Perca flavescens*), white perch (*Morone americana*), white bass (*Morona chrysops*) and walleye (*Stizostedion vitreum vitreum*) in Lake Erie (Bur et al. 1986, Bur and Klarer 1991), in pink and chinook salmon in Lake Superior (Cullis and Johnson 1988), and in deep-water sculpin (*Myoxocephalus thompsoni*), alewife (*Alosa pseudoharengus*), yellow perch and rock bass from Lake Michigan (Evans 1988, Keilty 1990, Schneeberger 1991). Makarewitz and Jones (1990) suggest that the alewife is responsible for maintaining the generally very low, open water densities of *B. cederstroemi* in Lake Ontario. Johannsson et al. (1991) noted that *B. cederstroemi* was readily detectable in the plankton of Lake Ontario only once during the 1980's. This was in 1987, the year with the smallest alewife population of the decade.

The European literature also provides many examples of *Bythotrephes* as preferred prey of several fish species, including, for example, adult perch (*Perca fluviatus*, Craig 1978), brown trout (*Salmo trutta*, Fitzmaurice 1979), smelt (*Osmerus eperlanus*, Næsje et al. 1987), *Coregonus* sp. (De Bernardi and Giussani 1975), and, in one of the most detailed studies, all pelagic fish species in Lake Vänern (Nilsson 1979). Only very small fish, for example 0+ perch (Guma'a 1978), have trouble handling *Bythotrephes*, apparently because of its long caudal process.

Bythotrephes consumes planktonic rotifers, Crustacea and chironomids, preferring prey that are slow moving, i.e. Cladocera rather than copepods. Among daphnids, *B. cederstroemi* apparently prefers small, un-helmeted species to larger or luxuriantly helmeted species

(Lehman in press). After *B. cederstroemi* has captured its prey, it tears it up, then it sucks in the fragments, often quite inefficiently for larger prey (Monakov 1972, Lehman pers. comm.).

In summary, many Canadian Shield lakes provide suitable habitat for *B. cederstroemi*. Its colonization of Shield lakes will probably not be restricted by low dispersal capability. The movement of people and their recreational vehicles among the developed lakes of southern Ontario will undoubtedly speed the dispersal of the species. The existing literature provides little information to guide our assessment of the impact of the invader on Shield lakes. Further, the North American students of *Bythotrephes* ecology do not all agree on the impacts of the invader on Great Lakes food webs. Nevertheless, it seems reasonable to suggest that *B. cederstroemi* will colonize Shield lakes with low levels of planktivorous fish with greatest success. In such lakes, we might anticipate reductions in the relative abundance of small daphnids. We can not say if reductions in the abundance of small daphnids will have any negative impacts on zooplankton predators.

The impacts of *B. cederstroemi* on Shield lakes will not be understood without additional research and monitoring programs. Obvious promising research initiatives include:

1) studies of the spatial distribution, migratory behaviour, production and life history of *B. cederstroemi* populations in Shield lakes with differing fish assemblages,
2) studies of the interaction of *B. cederstroemi* with other large, planktonic macro-invertebrate predators in Shield lakes, including mysids, mites, chaoborid larvae, and *Leptodora*,
3) studies of prey preferences of *B. cederstroemi* in Shield lakes,
4) comparisons of predation rates of *B. cederstroemi* with production rates of preferred prey, and
5) periodic studies of the spread of *B. cederstroemi* across the Shield.

Little or no historical zooplankton data exist for the vast majority of Shield lakes that will be colonized by *B. cederstroemi*. Paleolimnological assessment of changes in zooplankton assemblages may be a fruitful avenue of research for such lakes (eg. Kitchell and Kitchell 1980).

4. ACKNOWLEDGEMENTS

We thank Claudiu Tudorancea for examining the current and historical samples from Lakes Muskoka, Rosseau and Joseph, Jeff Schuldt for informing us of the presence of *B. cederstroemi* in lakes in Minnesota, Stephen Taylor for his technical assistance, and Barbara Hutchinson for providing us with historical zooplankton samples from the study lakes. We also thank Robert Girard, Mark Stirling and several students for their field work. Finally, we thank Gary Sprules, Eddie Jin, Dave Berg, and John Lehman for stimulating discussions on the biology of the invader, Greg Mierle for his comments on a draft of this report, and Renée Morrison for her patience at the word processor.

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Table 1: Major fish species present in the thirteen study lakes (Ontario Ministry of Natural Resources, unpublished data)

	Species[1]										
Lake	**LT**	**BT**	**LW**	**LH**	**RS**	**NP**	**YP**	**WAL**	**SMB**	**LMB**	**CWS**
Bear	x		x				x		x		x
Fairy	x		x	x	x	x	x		x		x
Kawagama	x	x	x	x			x		x		x
Joseph	x		x	x	x	x	x	x	x	x	x
Muskoka	x		x	x	x	x	x	x	x	x	x
Lake of Bays	x		x	x	x		x		x		x
Rosseau	x		x	x	x	x	x	x	x	x	x
Vernon	x		x		x	x	x		x	x	x
Mary	x		x	x	x	x	x		x		x
Peninsula	x		x	x	x	x	x		x		x
Skeleton	x		x	x	x		x	x	x	x	x
Three Mile				x			x	x	x		x
Go Home						x	x	x	x	x	x

[1]Species abbreviation are as follows: LT-lake trout, BT-brook trout, LW-lake whitefish, LH-lake herring, RS-rainbow smelt, YP-yellow perch, NP-northern pike, WAL-walleye, SMB-smallmouth bass, LMB-largemouth bass, CWS-common white sucker.

Table 2: Summary of the location and morphometry of the study lakes, and the number of cottage properties on their shores.

Lake	Township	Latitude (°N)	Longitude (°W)	Elevation (m)	z_{max} (m)	Area (ha)	# of Properties[1]
Bear	Livingstone	45°20′	78°42′	355	37	95	
Fairy	Brunel	45°20′	79°11′	284	70	711	136
Go Home	Gibson	45°01′	79°53′	180	33	666	433
Joseph	Medora	45°11′	79°47′	225	93	5156	792
Kawagama	Sherborne	45°18′	78°45′	355	73	2819	900
Lake of Bays	Franklin	45°15′	79°04′	316	70	6904	1784
Mary	Brunel	45°15′	79°15′	281	56	1065	248
Muskoka	Muskoka	45°00′	79°25′	225	67	12200	3986
Peninsula	Franklin	45°20′	79°06′	284	34	865	313
Rosseau	Cardwell	45°10′	79°35′	225	90	6374	907
Skeleton	Watt	45°15′	79°27′	281	65	2154	348
Three Mile	Watt	45°10′	79°27′	247	11	929	340
Vernon	Stisted	45°20′	79°17′	284	37	1505	337

[1]The small number of properties on Bear Lake are included with the Kawagama Lake total. The property owners' associations of Kawagama and Go Home Lakes provided counts of the numbers of properties on their lakes. All other counts of cottage properties were provided by the Planning Office, District Municipality of Muskoka, July, 1991.

Table 3: Summary of selected water quality data[1] from the study lakes.

yLake	Sample date	pH	alk	Cond	DOC	TP	TN	Secchi
Bear	Jul 25/90	7.33	2.9	30	3.4	2.0	285	4.5
Fairy	Jul 26/90	7.39	5.50	47	4.5	5.5	530	2.5
Go Home	Jun 5/91	6.81	4.95	47	4.2	9.9	495	2.3
Joseph	Aug 11/86	6.75	3.16	48	2.4	3.0	290	7.4
Kawagama	Jul 25/90	7.02	3.90	30	2.4	3.0	285	9.0
Lake of Bays	Aug 11/86	6.73	3.55	36	2.9	4.0	310	6.3
Mary	Jul 26/90	7.01	5.50	49	4.6	4.0	520	3.0
Muskoka	Aug 11/86	6.79	4.64	44	3.4	5.0	420	5.1
Peninsula	Jul 26/90	7.26	9.60	60	3.7	6.0	275	4.0
Rosseau	Aug 11/86	6.83	4.40	43	2.9	4.0	380	6.4
Skeleton	Jul 24/90	7.01	3.90	42	1.8	0.5	540	10.5
Three Mile	Jul 24/90	6.91	11.4	69	5.4	11	350	1.5
Vernon	Jul 26/90	7.00	5.20	41	5.1	5.0	500	3.0

[1]alk (fixed endpoint alkalinity in mg/L as $CaCO_3$), Cond (Conductivity in μmhos/cm at 25°C), DOC (dissolved organic carbon in mg/L), TP (total phosphorus in μg/L), TN (total nitrogen in μg/L), Secchi transparency (depth in m). Data are from P.J. Dillon, Ontario Ministry of the Environment (unpublished data).

Table 4: Record of *B. cederstroemi* collections from Lake Joseph, 1989 and 1990.

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data	
					Number in Sample	Density ($\#/m^3$)
12-Jun-89	1	16.7	0.521	1.92		
10-Jul-89	1	17.0	0.530	1.89		
08-Aug-89	1	16.7	0.521	1.92		
12-Sep-89	1	16.7	0.665	1.50		
05-Oct-89	1	16.6	0.661	1.51		
30-May-90	1	17.0	0.677	1.47		
25-Jun-90	1	16.8	0.669	1.49		
24-Jul-90	1	16.8	0.669	1.49		
23-Aug-90	1	17.3	0.689	1.45		
20-Sep-90	1	17.3	0.689	1.45		
15-Oct-90	1	17.0	0.677	1.47		
12-Jun-89	3	16.5	0.515	1.94		
10-Jul-89	3	17.3	0.535	1.85		
08-Aug-89	3	15.0	0.468	2.14		
12-Sep-89	3	16.2	0.645	1.55		
05-Oct-89	3	16.4	0.653	1.53		
30-May-90	3	16.8	0.669	1.49		
25-Jun-90	3	16.5	0.657	1.52		
24-Jul-90	3	16.9	0.673	1.48		
23-Aug-90	3	16.3	0.649	1.54		
20-Sep-90	3	16.5	0.657	1.52		
15-Oct-90	3	16.4	0.653	1.53		
30-May-90	4	72.0	2.867	0.34		
25-Jun-90	4	73.0	2.907	0.34		
24-Jul-90	4	72.7	2.895	0.35	1	0.35
23-Aug-90	4	72.7	2.894	0.34		
20-Sep-90	4	72.9	2.903	0.34		
15-Oct-90	4	73.0	2.907	0.34		
12-Jun-89	5	31.0	0.967	1.03		
12-Jul-89	5	37.8	1.179	0.85	1	0.85
08-Aug-89	5	38.2	1.192	0.84		
12-Sep-89	5	38.1	1.517	0.66		
05-Oct-89	5	38.2	1.521	0.66		
28-May-90	5	38.1	1.517	0.65		
25-Jun-90	5	38.3	1.525	0.65		
24-Jul-90	5	37.9	1.509	0.66		

Table 4 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data: Number in Sample	Bythotrephes Data: Density ($\#/m^3$)
23-Aug-90	5	38.5	1.533	0.65		
19-Sep-90	5	38.0	1.513	0.66		
15-Oct-90	5	37.9	1.509	0.66		
12-Jun-89	6	18.6	0.580	1.72		
10-Jul-89	6	18.5	0.577	1.73		
08-Aug-89	6	18.5	0.577	1.73		
12-Sep-89	6	18.5	0.737	1.36		
05-Oct-89	6	18.5	0.737	1.36		
28-May-90	6	18.4	0.732	1.37		
25-Jun-90	6	18.5	0.737	1.36		
24-Jul-90	6	18.5	0.737	1.36		
23-Aug-90	6	18.9	0.753	1.32		
19-Sep-90	6	18.5	0.737	1.36		
15-Oct-90	6	18.5	0.737	1.36		
12-Jun-89	7	7.9	0.247	4.06		
10-Jul-89	7	7.6	0.237	4.22		
08-Aug-89	7	7.6	0.237	4.22		
12-Sep-89	7	7.7	0.307	3.26		
05-Oct-89	7	7.2	0.287	3.49		
28-May-90	7	7.7	0.306	3.26		
25-Jun-90	7	7.4	0.295	3.39		
25-Jul-90	7	7.5	0.299	3.34		
23-Aug-90	7	7.6	0.302	3.31		
19-Sep-90	7	7.4	0.295	3.39		
15-Oct-90	7	7.5	0.299	3.34		
28-May-90	8	35.4	1.409	0.71		
25-Jun-90	8	34.7	1.381	0.72		
25-Jul-90	8	34.4	1.37	0.73	1	0.73
23-Aug-90	8	34.7	1.382	0.72		
19-Sep-90	8	35.2	1.402	0.71	2	0.71
15-Oct-90	8	35.5	1.413	0.71		
12-Jun-89	9	31.0	0.967	1.03		
10-Jul-89	9	35.9	1.120	0.89		
10-Aug-89	9	35.8	1.117	0.90		
12-Sep-89	9	35.9	1.429	0.70		
05-Oct-89	9	35.5	1.413	0.71		

Table 4 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data: Number in Sample	Bythotrephes Data: Density ($\#/m^3$)
28-May-90	9	35.6	1.418	0.71		
25-Jun-90	9	35.7	1.422	0.70		
25-Jul-90	9	36.4	1.449	0.69		
23-Aug-90	9	35.7	1.426	0.70		
19-Sep-90	9	34.5	1.374	0.73		
15-Oct-90	9	36.5	1.453	0.69		
12-Jun-89	11	11.3	0.353	2.84		
12-Jul-89	11	11.2	0.349	2.86	1	2.86
10-Aug-89	11	11.3	0.353	2.84		
12-Sep-89	11	11.0	0.438	2.28		
05-Oct-89	11	11.0	0.438	2.28		
28-May-90	11	11.3	0.450	2.22		
26-Jun-90	11	11.5	0.458	2.18		
25-Jul-90	11	11.6	0.462	2.16		
23-Aug-90	11	11.5	0.457	2.19		
19-Sep-90	11	11.5	0.457	2.19		
16-Oct-90	11	11.3	0.450	2.22		

[1] calculated assuming 1B. cederstroemi is caught in entire sample

Table 5: Record of *B. cederstroemi* collections from Lake Muskoka, 1989 and 1990

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data	
					Number in Sample	Density ($\#/m^3$)
05-Jun-89	1	15.6	0.487	2.05		
06-Jul-89	1	15.1	0.471	2.12		
01-Aug-89	1	15.2	0.474	2.11		
29-Aug-89	1	14.8	0.461	2.17	2	4.34
12-Oct-89	1	15.5	0.617	1.62	5	8.10
01-Jun-90	1	15.0	0.597	1.68		
27-Jun-90	1	14.5	0.577	1.73		
26-Jul-90	1	14.6	0.581	1.72	1	1.72
20-Aug-90	1	15.1	0.601	1.66		
17-Sep-90	1	14.7	0.585	1.71		
05-Jun-89	2	15.9	0.496	2.02		
06-Jul-89	2	13.0	0.406	2.47		
01-Aug-89	2	16.0	0.499	2.00		
29-Aug-89	2	15.8	0.492	2.03		
12-Oct-89	2	16.6	0.661	1.51	5	7.57
01-Jun-90	2	15.5	0.617	1.62		
27-Jun-90	2	16.4	0.653	1.53		
26-Jul-90	2	15.3	0.609	1.64		
20-Aug-90	2	15.6	0.621	1.61		
17-Sep-90	2	16.8	0.669	1.49		
05-Jun-89	3	15.6	0.487	2.05		
06-Jul-89	3	14.9	0.465	2.15		
31-Jul-89	3	14.9	0.593	1.69		
29-Aug-89	3	16.0	0.499	2.01		

Table 5 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data	
					Number in Sample	Density ($\#/m^3$)
12-Oct-89	3	15.3	0.609	1.64	3	4.93
01-Jun-90	3	15.2	0.605	1.60		
27-Jun-90	3	15.4	0.613	1.63		
26-Jul-90	3	15.4	0.613	1.63	1	1.63
20-Aug-90	3	15.1	0.601	1.66		
17-Sep-90	3	15.6	0.621	1.61		
05-Jun-89	4	12.3	0.384	2.61	1	2.61
06-Jul-89	4	12.3	0.384	2.60	1	2.60
31-Jul-89	4	12.3	0.490	2.04		
29-Aug-89	4	12.6	0.397	2.55		
11-Oct-89	4	11.8	0.469	2.13		
01-Jun-90	4	12.6	0.502	1.99		
27-Jun-90	4	12.3	0.490	2.04		
26-Jul-90	4	12.7	0.506	1.98		
20-Aug-90	4	12.2	0.486	2.06		
17-Sep-90	4	12.6	0.502	1.99		
01-Jun-90	5	52.7	2.099	0.48		
27-Jun-90	5	51.5	2.051	0.49	1	0.49
26-Jul-90	5	52.2	2.079	0.48	1	0.48
20-Aug-90	5	52.0	2.071	0.48		
17-Sep-90	5	49.0	1.951	0.51		
05-Jun-89	6	11.0	0.343	2.91		
05-Jul-89	6	10.3	0.321	3.11		
31-Jul-89	6	10.1	0.402	2.49		

Table 5 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data: Number in Sample	Bythotrephes Data: Density ($\#/m^3$)
29-Aug-89	6	10.8	0.337	2.97		
11-Oct-89	6	10.3	0.410	2.44		
01-Jun-90	6	11.0	0.438	2.28		
27-Jun-90	6	10.5	0.418	2.39		
26-Jul-90	6	10.7	0.426	2.35		
20-Aug-90	6	10.8	0.430	2.33		
17-Sep-90	6	11.0	0.438	2.28		
05-Jun-89	8	18.3	0.571	1.75		
05-Jul-89	8	18.0	0.562	1.78	1	1.78
31-Jul-89	8	17.7	0.705	1.42		
29-Aug-89	8	18.2	0.567	1.76		
11-Oct-89	8	17.8	0.709	1.41		
01-Jun-90	8	18.2	0.724	1.38		
28-Jun-90	8	18.2	0.724	1.38	1	1.38
25-Jul-90	8	17.9	0.712	1.40	1	1.4
20-Aug-90	8	17.7	0.705	1.41		
18-Sep-90	8	17.7	0.705	1.42		
17-Oct-90	8	17.8	0.709	1.41		
01-Jun-90	10	22.6	0.900	1.11		
28-Jun-90	10	17.6	0.701	1.43	1	1.43
25-Jul-90	10	18.9	0.753	1.33		
21-Aug-90	10	19.2	0.764	1.31		
18-Sep-90	10	19.6	0.78	1.28		
01-Jun-90	11	65.3	2.600	0.38		

Table 5 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data	
					Number in Sample	Density ($\#/m^3$)
28-Jun-90	11	64.7	2.576	0.39		
25-Jul-90	11	64.9	2.584	0.39		
21-Aug-90	11	65.0	2.588	0.39		
18-Sep-90	11	64.7	2.576	0.39		
05-Jun-89	12	5.6	0.175	5.72		
05-Jul-89	12	5.5	0.177	5.83	1	5.83
31-Jul-89	12	5.4	0.215	4.65		
29-Aug-89	12	5.3	0.165	6.05		
03-Oct-89	12	5.3	0.211	4.74		
01-Jun-90	12	5.7	0.227	4.41		
28-Jun-90	12	5.5	0.219	4.57		
25-Jul-90	12	5.5	0.219	4.57		
21-Aug-90	12	5.8	0.231	4.33		
17-Sep-90	12	5.4	0.215	4.65		
05-Jun-89	13	13.4	0.418	2.39		
06-Jul-89	13	13.4	0.418	2.39		
01-Aug-89	13	13.3	0.415	2.41		
29-Aug-89	13	13.0	0.405	2.47	1	2.47
12-Oct-89	13	13.4	0.534	1.87	7	13.12
01-Jun-90	13	13.4	0.534	1.87		
27-Jun-90	13	13.2	0.526	1.90	1	1.9
25-Jul-90	13	13.2	0.526	1.90		
20-Aug-90	13	13.4	0.534	1.87		
17-Sep-90	13	13.3	0.530	1.89		

Table 5 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data	
					Number in Sample	Density ($\#/m^3$)
05-Jun-89	14	8.3	0.259	3.86		
06-Jul-89	14	8.1	0.253	3.96		
01-Aug-89	14	8.0	0.250	4.01	1	4.01
29-Aug-89	14	8.1	0.252	3.96	1	3.96
12-Oct-89	14	8.5	0.338	2.96	4	11.82

[1] see Table 4 for method of calculation.

Table 6: Record of *B. cederstroemi* collections from Lake Rosseau, 1989 and 1990.

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] (#/m^3)	Bythotrephes Data	
					Number in Sample	Density (#/m^3)
14-Jun-89	1	10.6	0.331	3.02		
11-Jul-89	1	10.6	0.331	3.02		
09-Aug-89	1	10.5	0.328	3.05		
11-Sep-89	1	10.5	0.418	2.39		
10-Oct-89	1	10.4	0.414	2.42		
31-May-90	1	10.6	0.422	2.37		
26-Jun-90	1	10.5	0.418	2.39		
23-Jul-90	1	10.5	0.418	2.39		
21-Aug-90	1	10.6	0.422	2.37		
19-Sep-90	1	10.5	0.418	2.39		
16-Oct-90	1	10.4	0.414	2.42		
14-Jun-89	2	23.4	0.730	1.37		
11-Jul-89	2	22.7	0.708	1.41		
09-Aug-89	2	23.0	0.718	1.39		
11-Sep-89	2	22.5	0.896	1.12	2	2.23
10-Oct-89	2	21.5	0.856	1.17	1	1.17
31-May-90	2	21.8	0.868	1.15		
26-Jun-90	2	22.1	0.880	1.14		
23-Jul-90	2	21.9	0.872	1.15		
21-Aug-90	2	22.6	0.900	1.11		
19-Sep-90	2	22.5	0.896	1.12		
16-Oct-90	2	22.5	0.896	1.12	1	1.11
14-Jun-89	4	17.7	0.552	1.81		
11-Jul-89	4	17.8	0.555	1.80		
09-Aug-89	4	17.9	0.559	1.79		
11-Sep-89	4	17.9	0.713	1.40		
10-Oct-89	4	17.8	0.709	1.41		
31-May-90	4	18.1	0.721	1.39		
26-Jun-90	4	18.5	0.737	1.36		
23-Jul-90	4	18.0	0.717	1.39		

Table 6 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] (#/m^3)	Bythotrephes Data: Number in Sample	Bythotrephes Data: Density (#/m^3)
21-Aug-90	4	17.9	0.713	1.40		
19-Sep-90	4	18.2	0.725	1.38		
16-Oct-90	4	18.4	0.733	1.36		
31-May-90	6	33.0	1.314	0.76		
26-Jun-90	6	32.7	1.302	0.77		
24-Jul-90	6	32.8	1.307	0.77		
22-Aug-90	6	32.2	1.282	0.78	3	2.34
18-Sep-90	6	32.5	1.294	0.77	4	3.09
16-Oct-90	6	32.6	1.298	0.77		
15-Jun-89	7	11.9	0.371	2.69		
11-Jul-89	7	11.6	0.362	2.76		
09-Aug-89	7	11.7	0.365	2.74		
11-Sep-89	7	11.7	0.466	2.15	1	2.15
10-Oct-89	7	11.6	0.462	2.17	3	6.50
31-May-90	7	12.0	0.478	2.09		
26-Jun-90	7	11.9	0.474	2.11		
24-Jul-90	7	11.7	0.466	2.15		
22-Aug-90	7	11.8	0.470	2.13		
18-Sep-90	7	12.2	0.486	2.06		
16-Oct-90	7	11.5	0.458	2.18		
15-Jun-89	8	4.6	0.144	6.97		
10-Jul-89	8	3.7	0.115	8.67		
10-Aug-89	8	3.3	0.103	9.71		
11-Sep-89	8	3.2	0.127	7.85		
10-Oct-89	8	3.5	0.139	7.18		
31-May-90	8	3.9	0.155	6.45		
26-Jun-90	8	3.9	0.155	6.45		
24-Jul-90	8	4.0	0.159	6.29		
22-Aug-90	8	4.3	0.171	5.85	3	17.5
18-Sep-90	8	4.0	0.159	6.29		

Table 6 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] (#/m^3)	Bythotrephes Data	
					Number in Sample	Density (#/m^3)
16-Oct-90	8	3.7	0.147	6.80		
15-Jun-89	9	6.9	0.215	4.64		
12-Jul-89	9	6.7	0.209	4.79	1	4.79
10-Aug-89	9	6.8	0.212	4.71		
11-Sep-89	9	6.8	0.271	3.69		
10-Oct-89	9	6.7	0.267	3.75		
31-May-90	9	7.2	0.287	3.48		
26-Jun-90	9	7.0	0.278	3.60		
24-Jul-90	9	6.9	0.275	3.64		
22-Aug-90	9	6.9	0.275	3.64		
18-Sep-90	9	6.8	0.271	3.70	1	3.69
16-Oct-90	9	6.7	0.267	3.75	2	7.49
14-Jun-89	10	13.1	0.409	2.45		
11-Jul-89	10	13.3	0.415	2.41		
09-Aug-89	10	13.3	0.415	2.41		
11-Sep-89	10	13.0	0.518	1.93		
10-Oct-89	10	13.4	0.534	1.87		
31-May-90	10	13.2	0.526	1.90		
26-Jun-90	10	13.3	0.530	1.89		
23-Jul-90	10	13.2	0.526	1.90		
22-Aug-90	10	13.5	0.538	1.86		
18-Sep-90	10	13.2	0.526	1.90		
15-Oct-90	10	13.4	0.534	1.80		
31-May-90	11	46.1	1.836	0.54		
26-Jun-90	11	45.9	1.828	0.55		
23-Jul-90	11	45.8	1.824	0.55		
21-Aug-90	11	45.7	1.820	0.55	1	0.55
18-Sep-90	11	45.8	1.824	0.55	4	2.19
15-Oct-90	11	45.7	1.820	0.55		
31-May-90	12	85.6	3.409	0.29		

Table 6 (cont'd)

Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data: Number in Sample	Bythotrephes Data: Density ($\#/m^3$)
26-Jun-90	12	86.7	3.452	0.29	1	0.29
23-Jul-90	12	86.5	3.444	0.29	3	0.87
21-Aug-90	12	86.5	3.444	0.29	1	0.29
19-Sep-90	12	86.2	3.432	0.29		
16-Oct-90	12	86.4	3.440	0.29		

[1] See Table 4 for method of calculation.

Table 7: Record of *B. cederstroemi* collections from Bear Lake, Fairy Lake, Go Home Lake, Kawagama Lake, Lake of Bays, Mary Lake, Peninsula Lake, Skeleton Lake, Three Mile Lake and Lake Vernon

Lake	Sampling Date	Station	Station Depth (m)	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] ($\#/m^3$)	Bythotrephes Data	
							Number in Sample	Density ($\#/m^3$)
Bear	25-Jul-90	1	9	7.0	0.73	1.37		
Fairy	26-Jul-90	9	75	30.0	2.97	0.34		
	23-Aug-90	1	19	17.0	1.79	0.56	11	6.16
	23-Aug-90	2	12	10.0	0.98	1.02	1	1.02
	23-Aug-90	3	18	16.0	1.42	0.70		
	23-Aug-90	4	19	17.0	1.68	0.60	2	1.19
	23-Aug-90	5	7	5.0	0.38	2.61	3	7.83
	23-Aug-90	6	14	12.0	1.24	0.81		
	23-Aug-90	7	18	16.0	1.26	0.80	2	1.59
	23-Aug-90	8	22	20.0	2.10	0.48		
	23-Aug-90	9	75	30.0	2.88	0.35		
	06-Jun-91	1	17	15.6	1.28	0.78	32	25.09
	06-Jun-91	5	7	5.3	0.53	1.89	4	7.57
	06-Jun-91	9	75	30.6	[2]5.47	0.18	24	4.39
Go Home	05-Jun-91	1	24	18.7	[2]3.88	0.26		
	05-Jun-91	2	20	16.7	1.40	0.71		
	05-Jun-91	4	20	18.7	1.88	0.53		
	05-Jun-91	5	27	27.5	2.92	0.34		
	05-Jun-91	6	6	6.3	0.66	1.52	2	3.05
Kawagama	25-Jul-90	1	7	5.0	0.56	1.79		
	25-Jul-90	2	43	30.0	2.59	0.39		
	25-Jul-90	3	43	30.0	3.01	0.33		
	25-Jul-90	4	49	30.0	2.79	0.36		
	25-Jul-90	5	61	30.0	2.92	0.34		
	25-Jul-90	6	8	5.5	0.60	1.66		
Lake of Bays	01-Aug-90	1	9	7.0	0.89	1.12		
	01-Aug-90	2	17	15.0	1.49	0.67		
	01-Aug-90	3	12	10.0	1.04	0.96		
	01-Aug-90	4	10	8.3	0.91	1.10		

Table 7 (cont'd)

Lake	Sampling Date	Station	Station Depth (m)	Haul Length (m)	Sample Volume (m^3)	Detection Limit[1] (#/m^3)	Bythotrephes Data: Number in Sample	Bythotrephes Data: Density (#/m^3)
	01-Aug-90	5	17	15.0	1.60	0.62		
	01-Aug-90	6	12	10.0	1.09	0.91		
	01-Aug-90	7	22	20.0	1.80	0.55		
	01-Aug-90	8	14	12.0	1.24	0.81		
	01-Aug-90	9	27	25.0	2.53	0.39		
	01-Aug-90	10	27	25.0	2.22	0.45		
	01-Aug-90	11	19	17.0	1.64	0.61		
	01-Aug-90	12	27	25.0	2.37	0.42		
Mary	26-Jul-90	1	35	30.0	3.21	0.31	1	0.31
	26-Jul-90	2	5	3.0	0.36	2.75	2	5.50
	26-Jul-90	3	57	30.0	3.13	0.32	2	0.64
	26-Jul-90	3	57	30.0	3.01	0.33	4	1.33
	26-Jul-90	4	26	24.0	2.24	0.45	2	0.89
	26-Jul-90	5	5	3.0	0.40	2.53		
	26-Jul-90	6	5	3.0	0.43	2.34		
Peninsula	26-Jul-90	1	15	13.0	1.31	0.76		
	26-Jul-90	2	32	30.0	2.19	0.46		
	06-Jun-91	1	20	15.6	[2]2.70	0.37		
	06-Jun-91	2	32	25.3	[2]4.14	0.24		
Skeleton	24-Jul-90	1	7	5.0	0.61	1.64		
	24-Jul-90	2	17	15.0	1.39	0.72		
	24-Jul-90	3	42	35.0	2.92	0.34		
Three Mile	24-Jul-90	1	4	2.0	0.29	3.45		
	24-Jul-90	2	4	2.0	0.24	4.17		
	24-Jul-90	3	6	8.0	0.76	1.32		
	24-Jul-90	4	4	2.0	0.27	3.70		
Vernon	26-Jul-90	1	35	30.0	[2]4.82	0.207		
	26-Jul-90	2	11	8.5	0.76	1.32		
	06-Jun-90	1	35	30.0	2.41	0.42		

[1] See Table 4 for detection limit calculations

[2] Contents of two hauls of indicated length were pooled.

Table 8: Occurrence of *B. cederstroemi* in surface horizontal hauls with 500 μm (for Peninsula Lake and Lake Vernon) and 150 μm (for Go Home Lake) tow nets.

Lake	Sampling Date	Station	Haul Length (m)	Sample Volume (m^3)	Detection Limit ($\#/m^3$)	Bythotrephes Data: Number in Sample	Bythotrephes Data: Density ($\#/m^3$)
Go Home	05-Jun-91	3	100	9.66	0.1		
Peninsula	06-Jun-91	1	25	4.72	0.21	11	2.33
Vernon	06-Jun-91	3	100	18.86	0.05	6	0.32

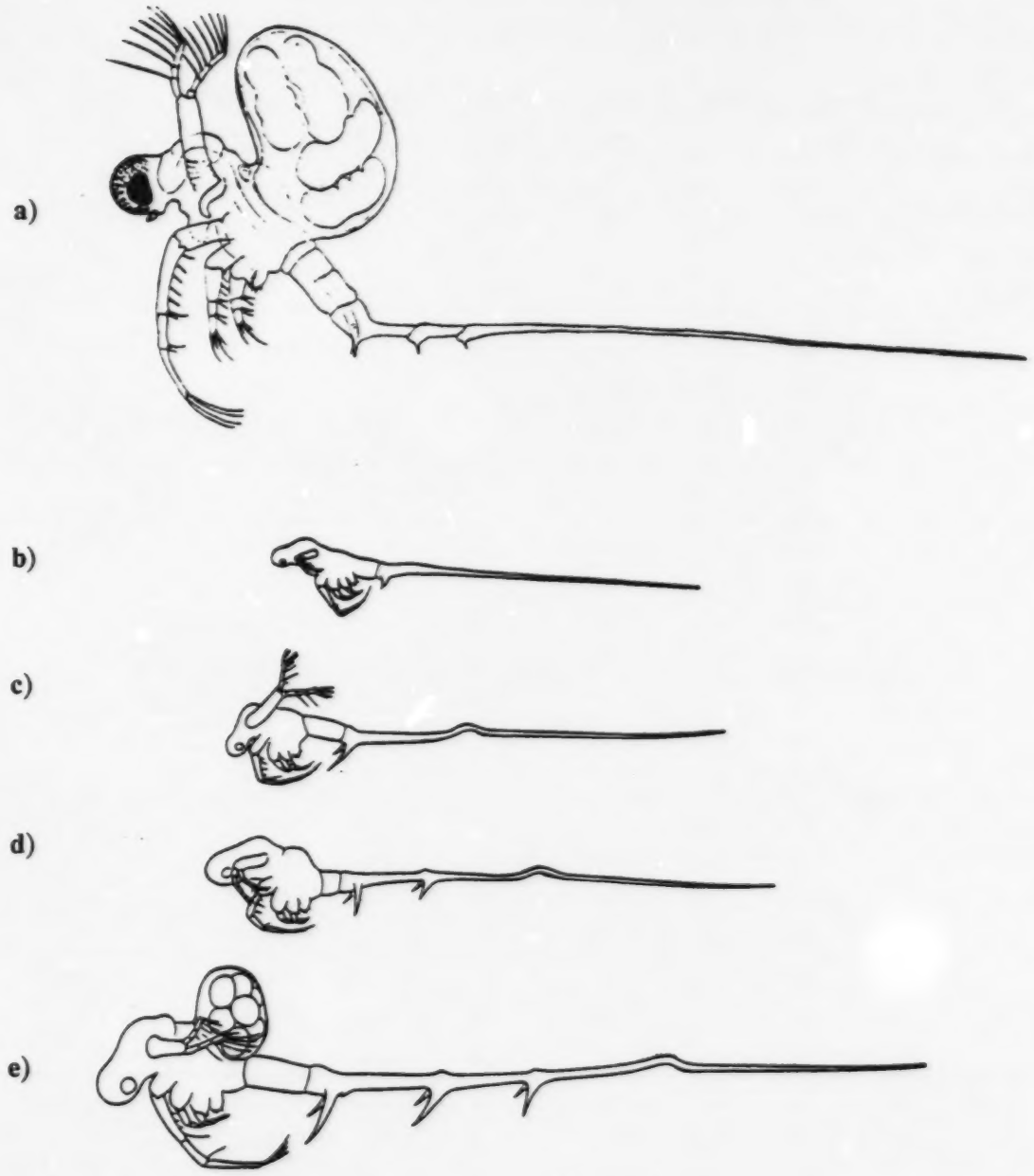

Figure 1 Habit sketch of *B. longimanus* (a - mature female from Mordukhai-Boltovskoi, 1968) and *B. cederstroemi* (b to e - from Lake Michigan, from Evans, 1988). Note the addition of lateral spines on the caudal process with development (c, d and e), and the difference in kinking of the caudal process between animals caught in Lake Michigan in July (b) vs. October (c). The body length of mature animals is about 13 mm.

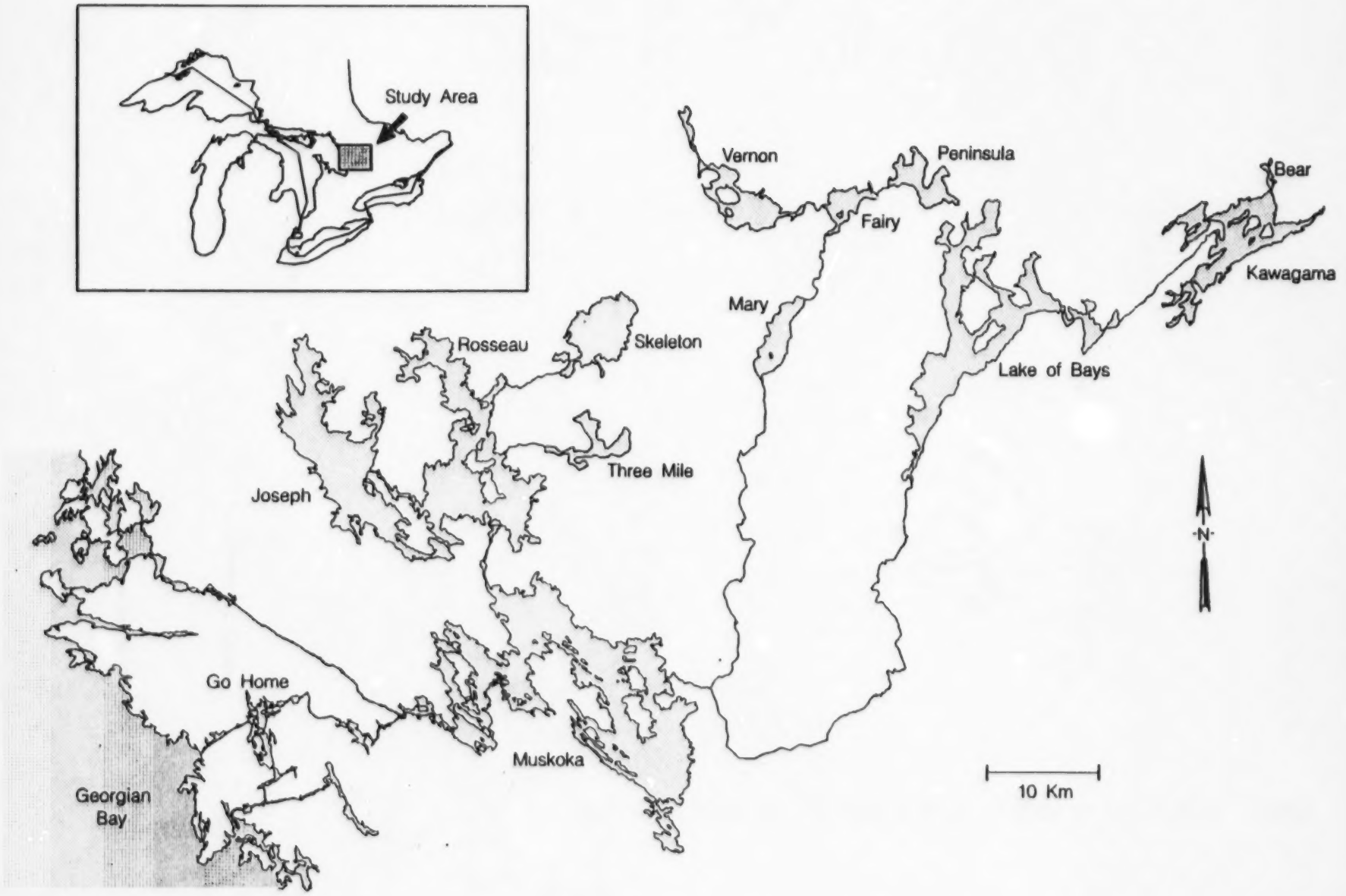

Figure 2: Location of study lakes in the Moon/Go Home Watershed

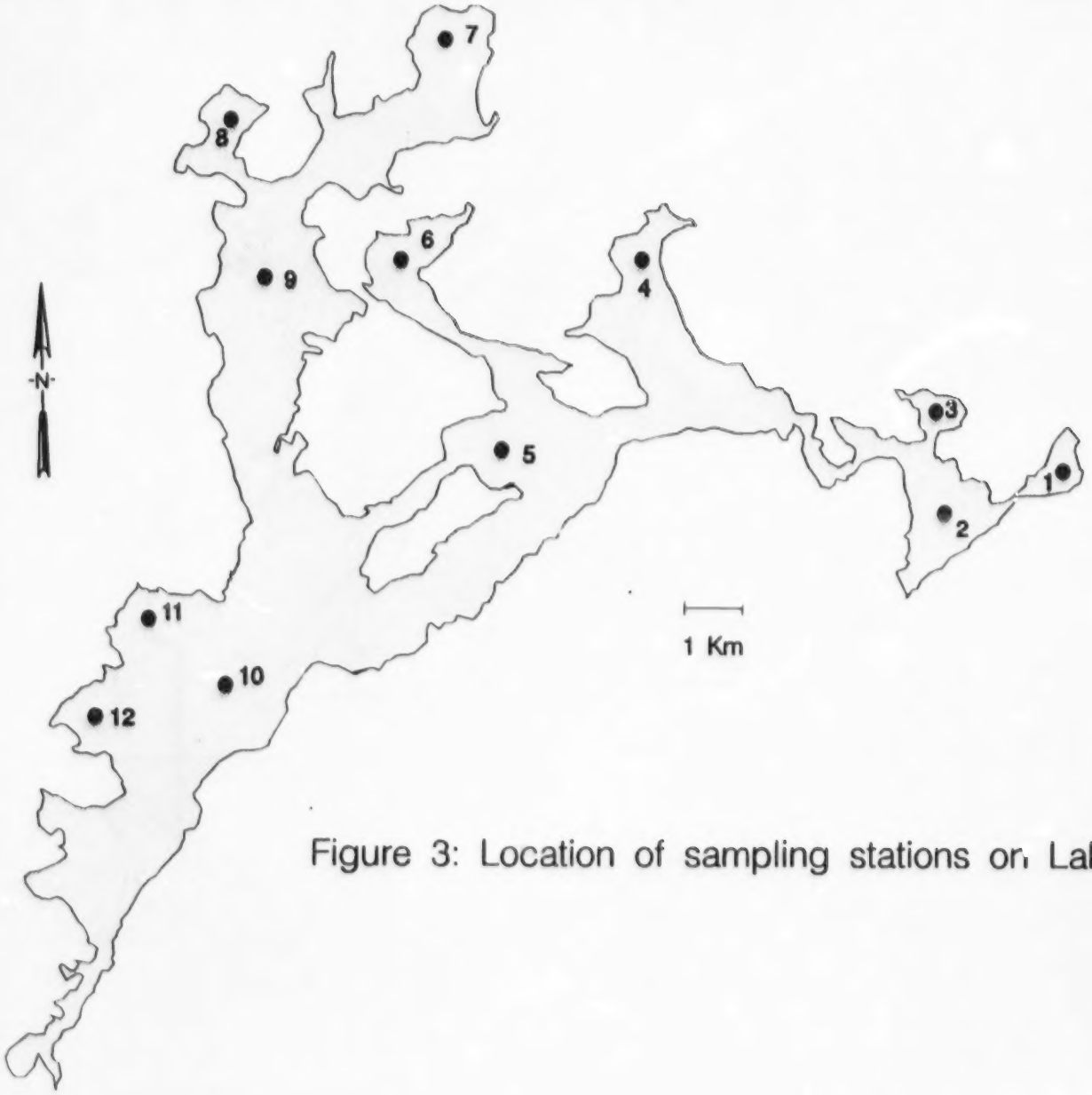

Figure 3: Location of sampling stations on Lake of Bays

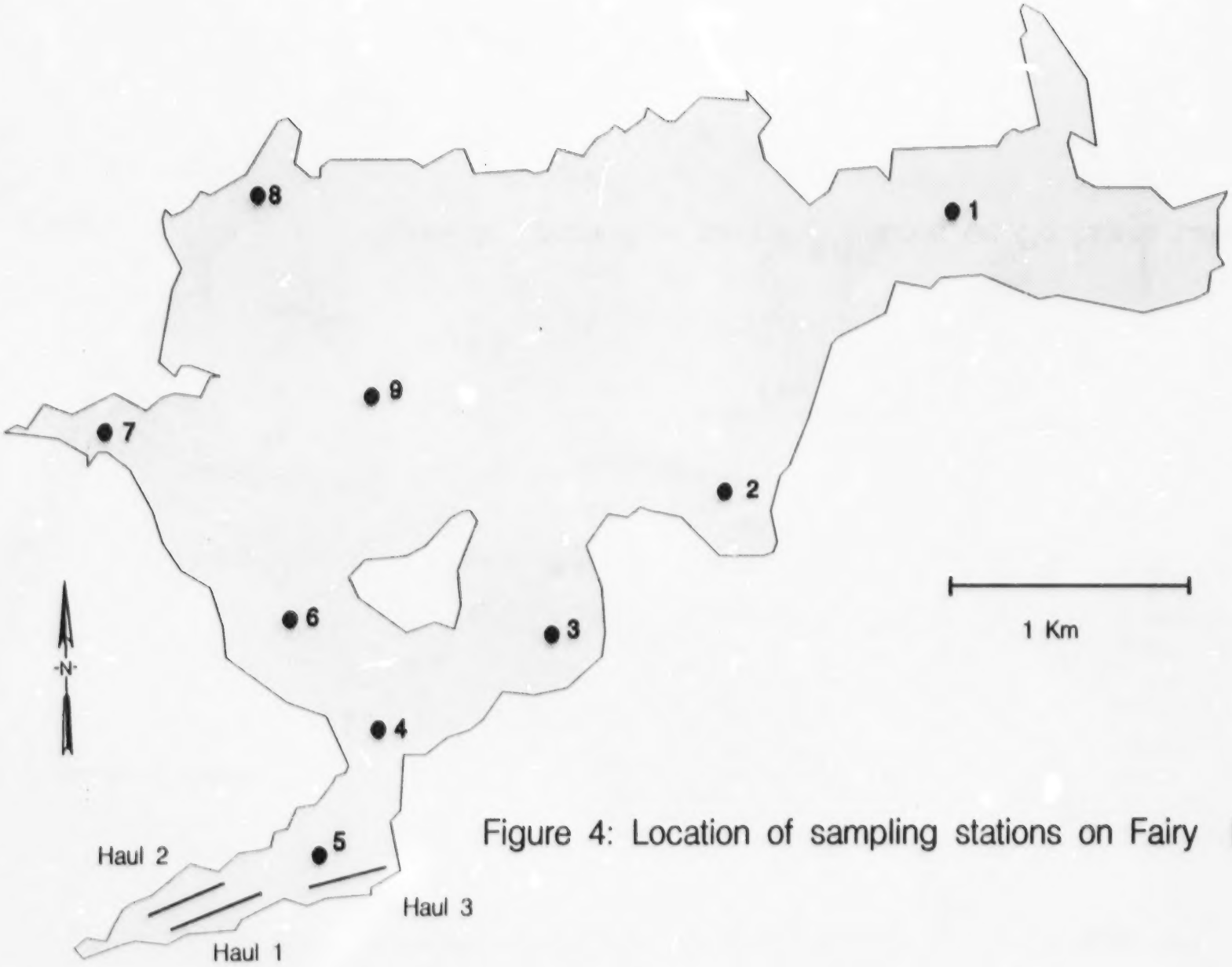

Figure 4: Location of sampling stations on Fairy Lake

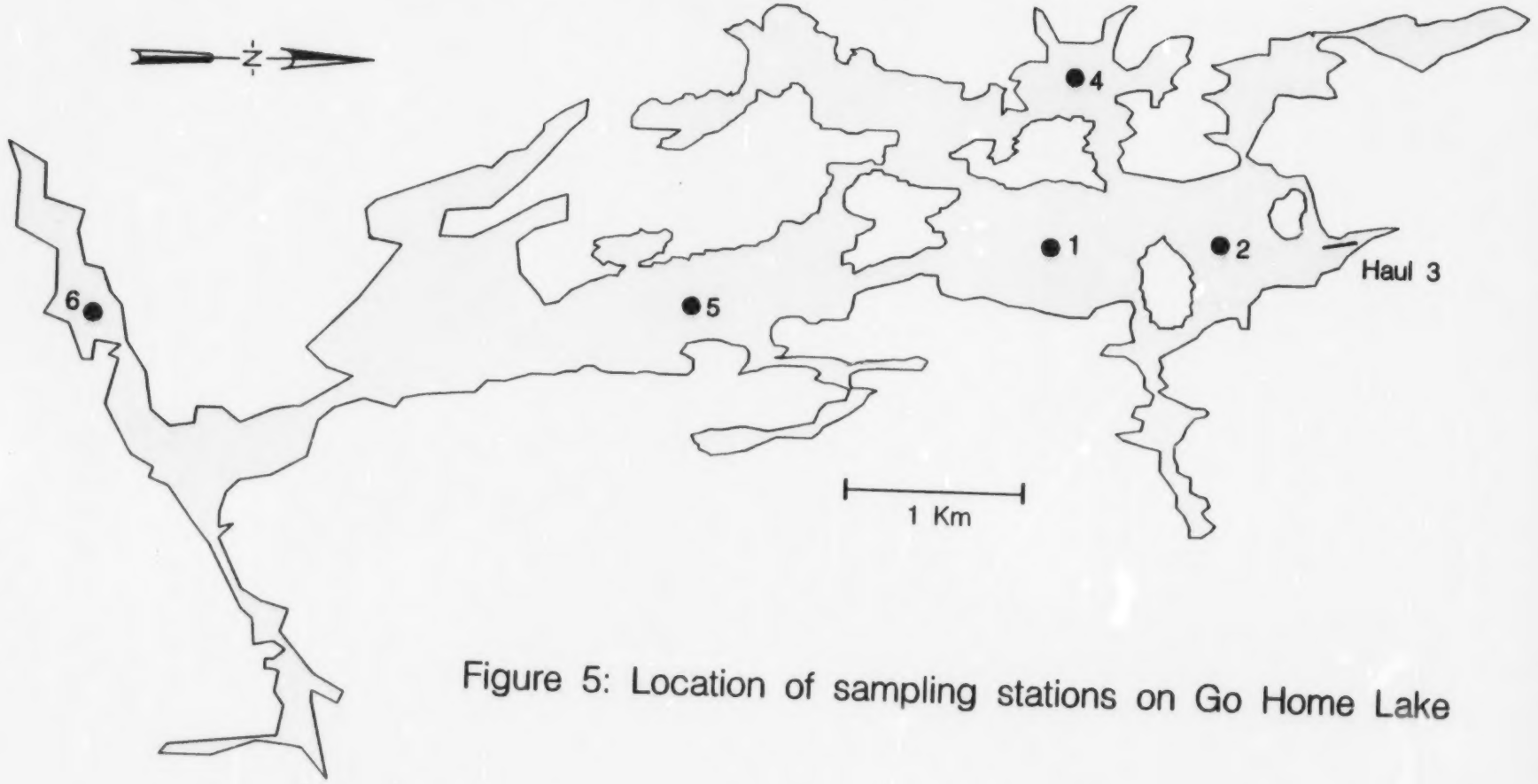

Figure 5: Location of sampling stations on Go Home Lake

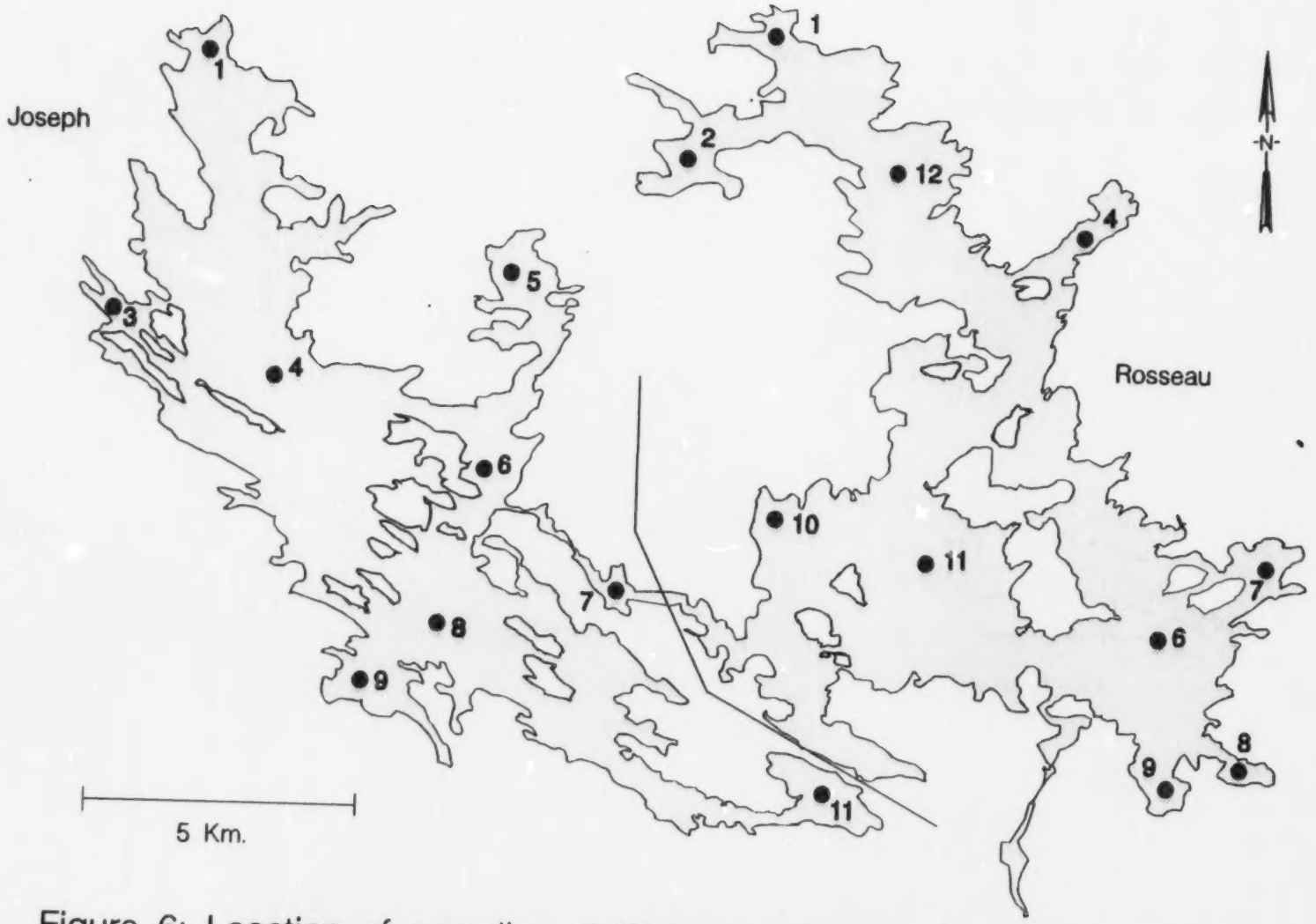

Figure 6: Location of sampling stations on Lake Joseph and Lake Rosseau

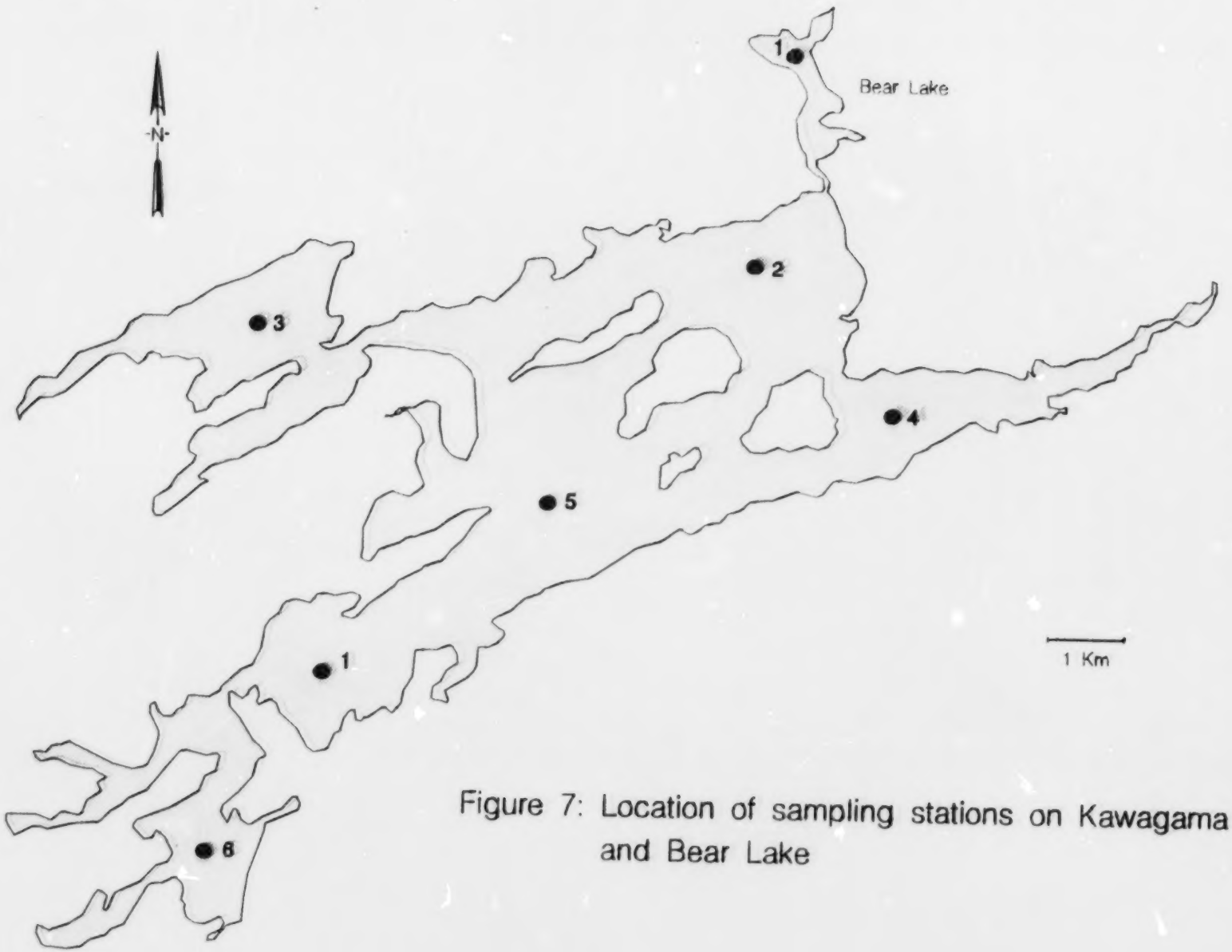

Figure 7: Location of sampling stations on Kawagama Lake and Bear Lake

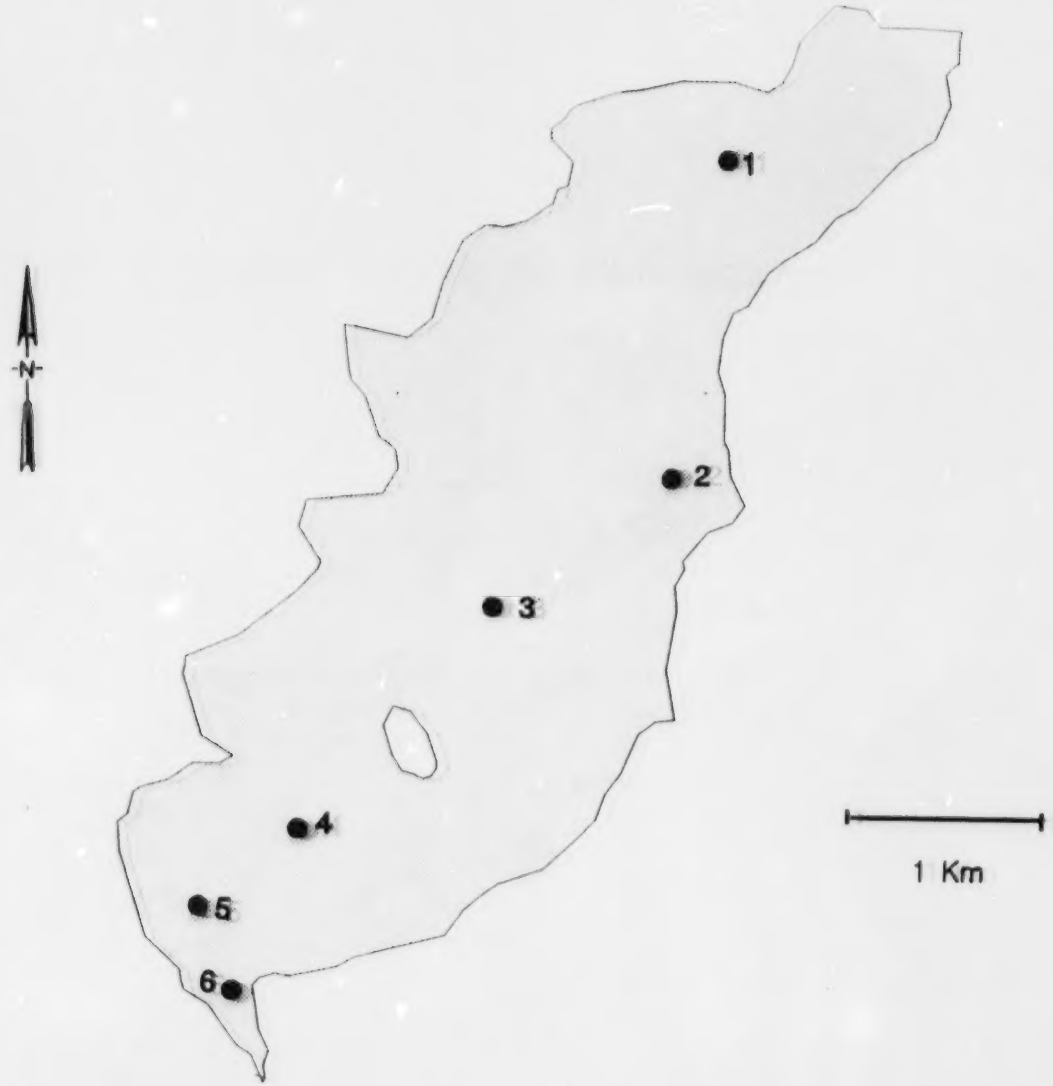

Figure 8: Location of sampling stations on Mary Lake

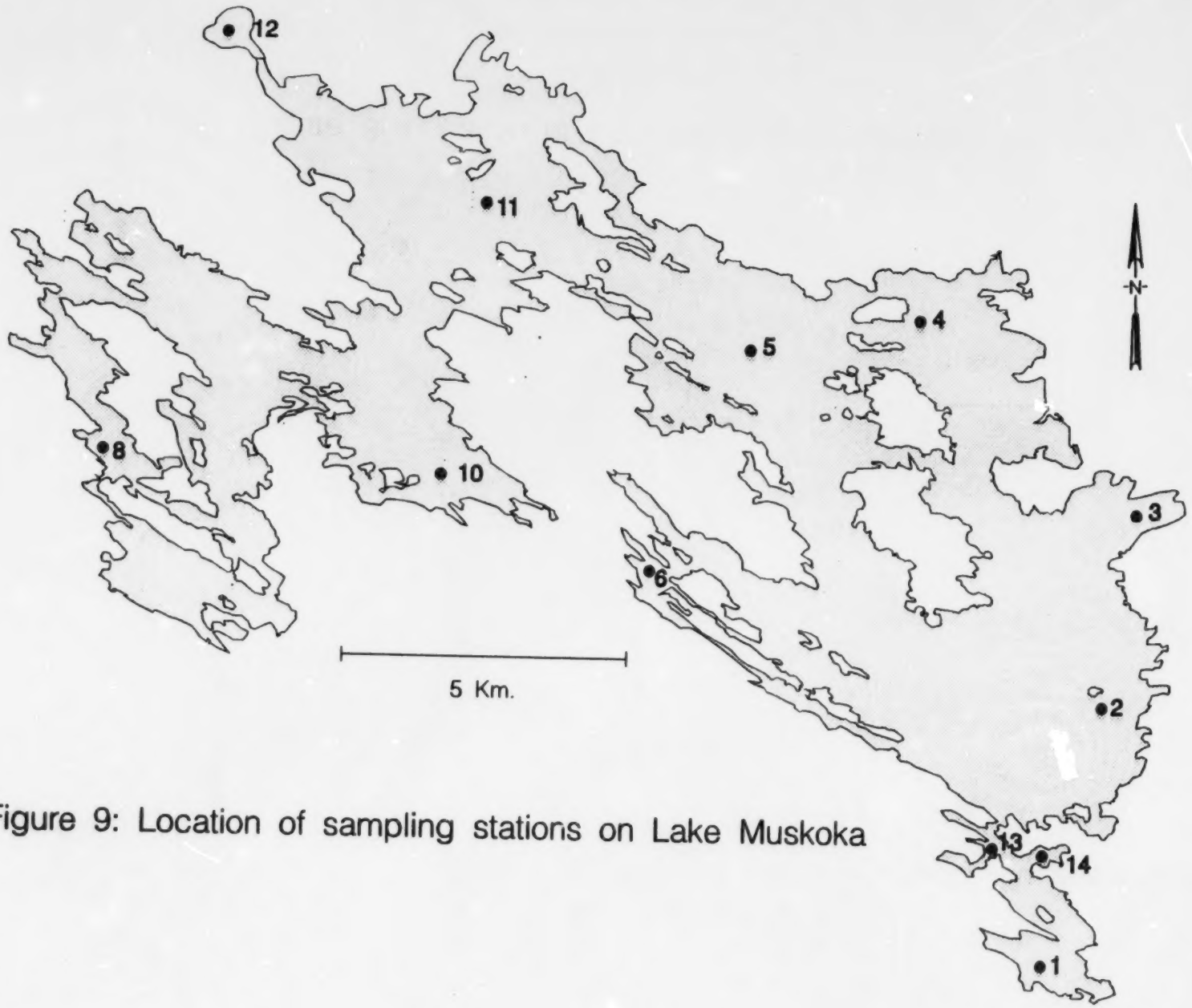

Figure 9: Location of sampling stations on Lake Muskoka

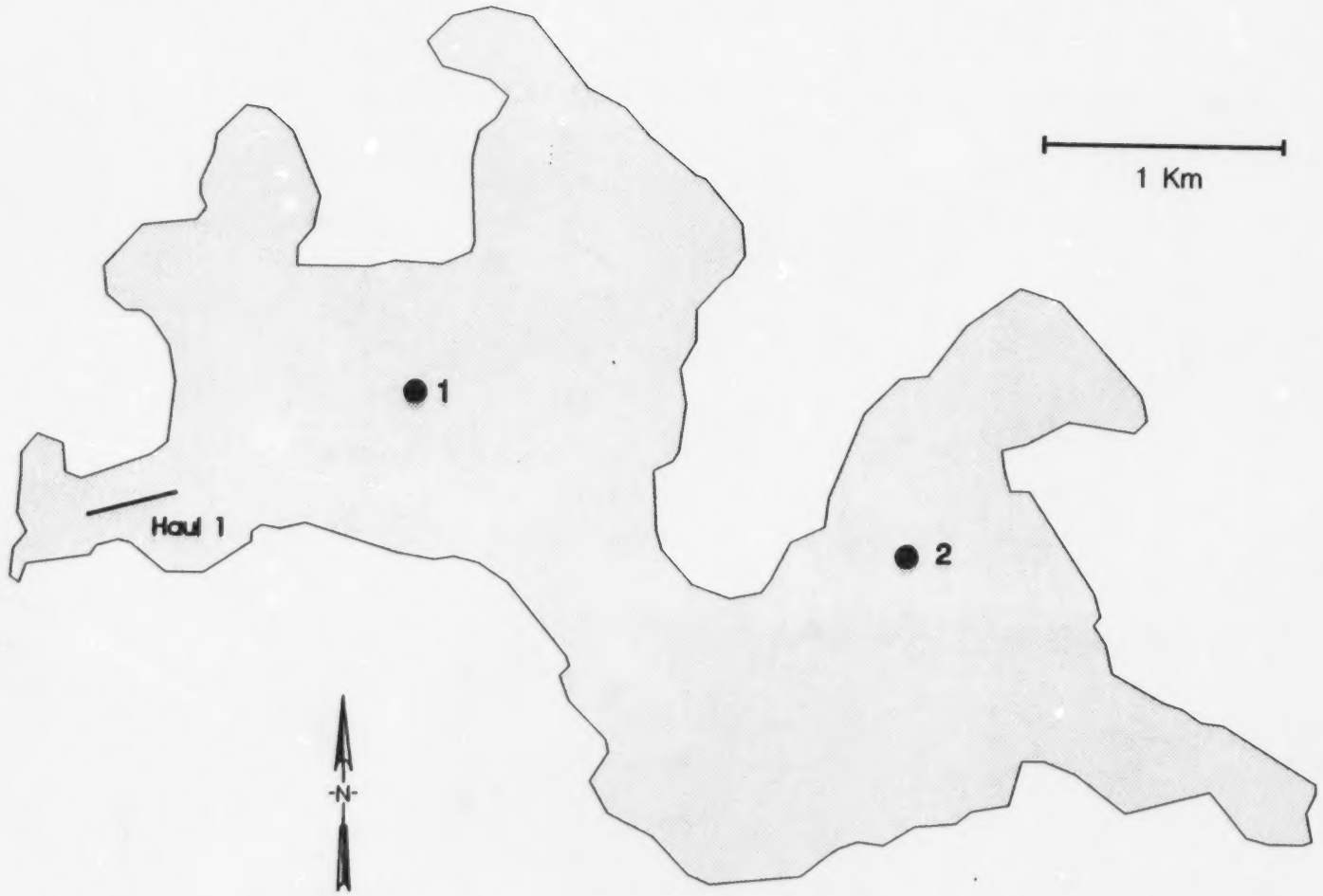

Figure 10: Location of sampling stations on Peninsula Lake

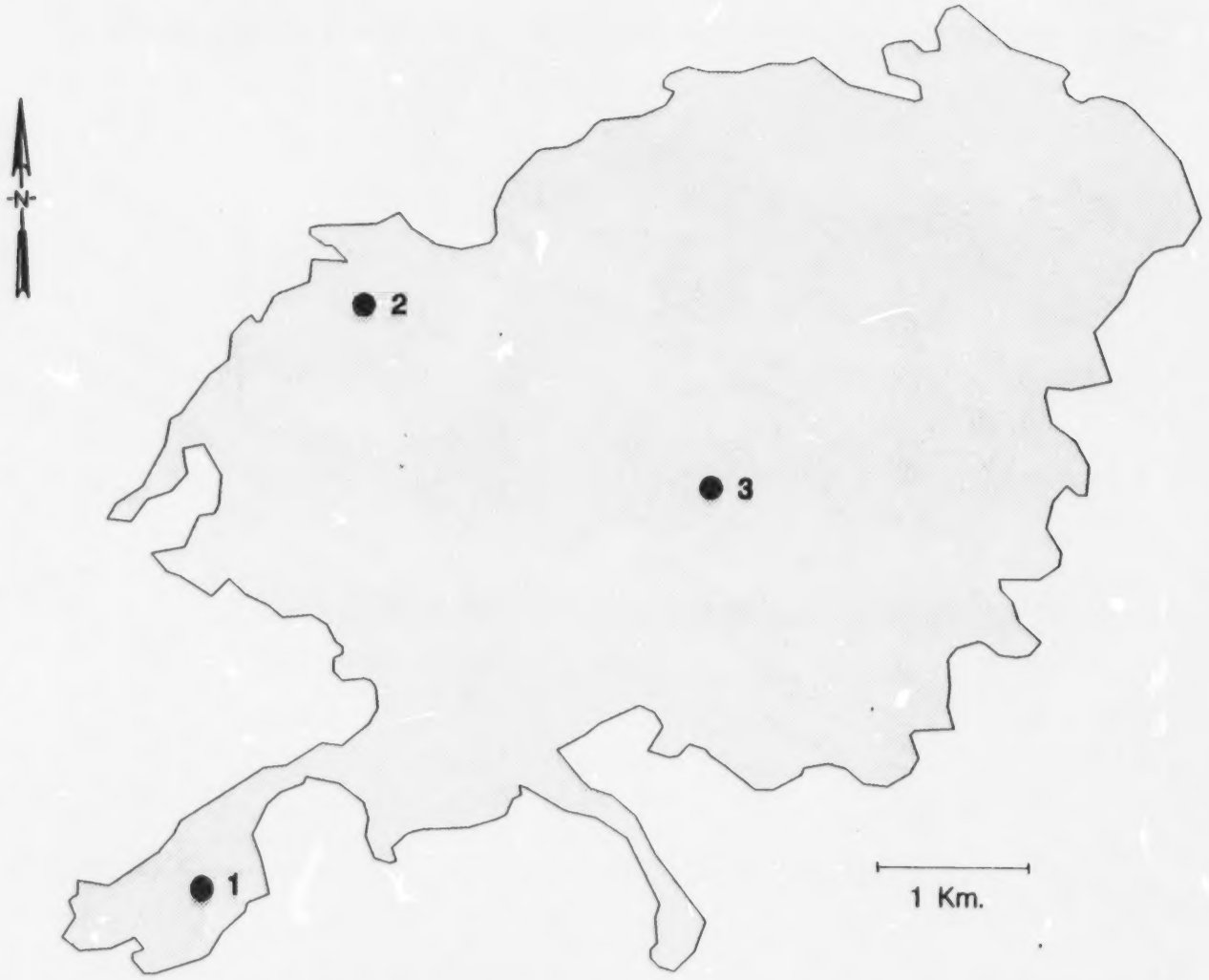

Figure 11: Location of sampling stations on Skeleton Lake

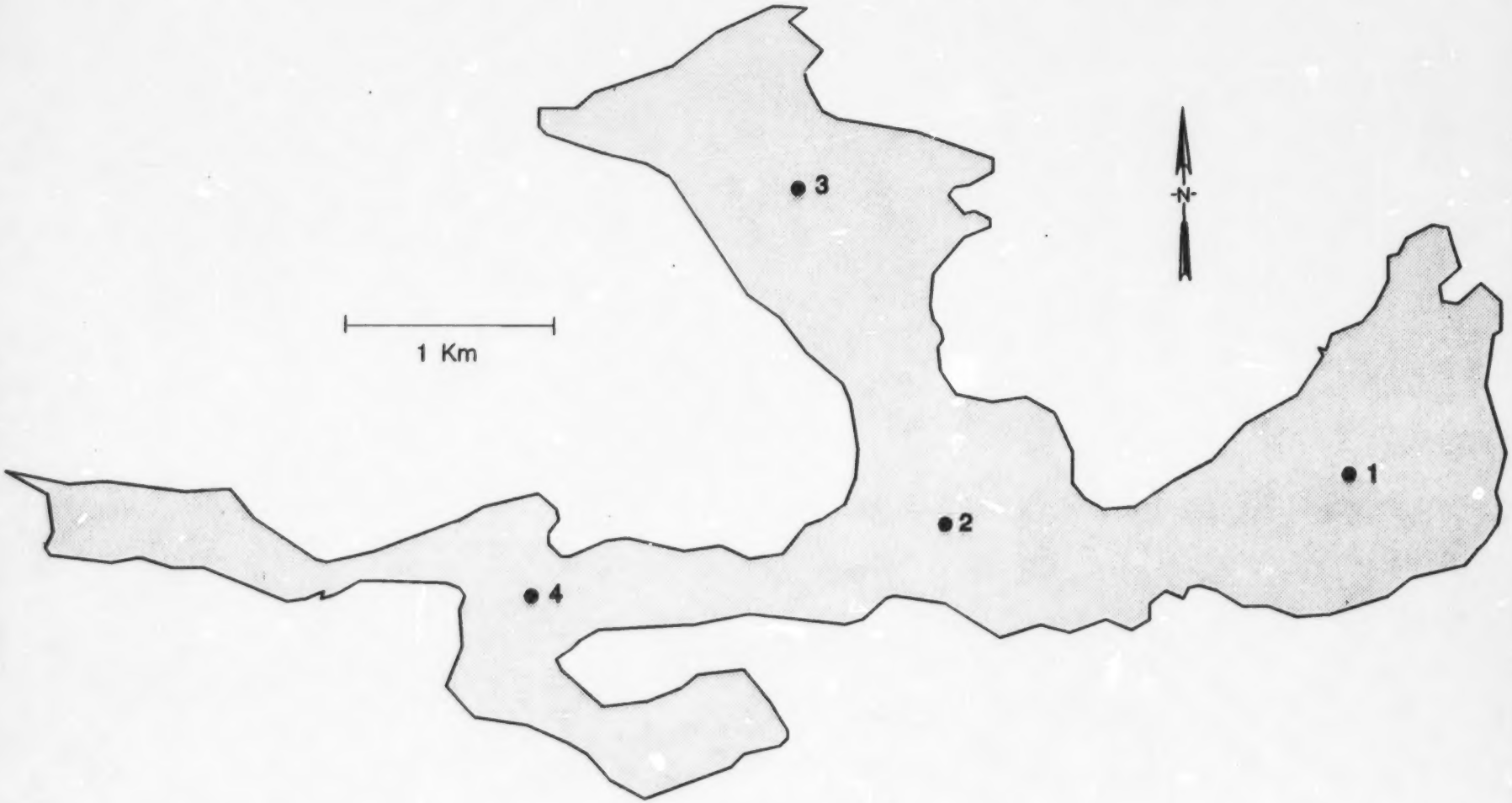

Figure 12: Location of sampling stations on Three Mile Lake

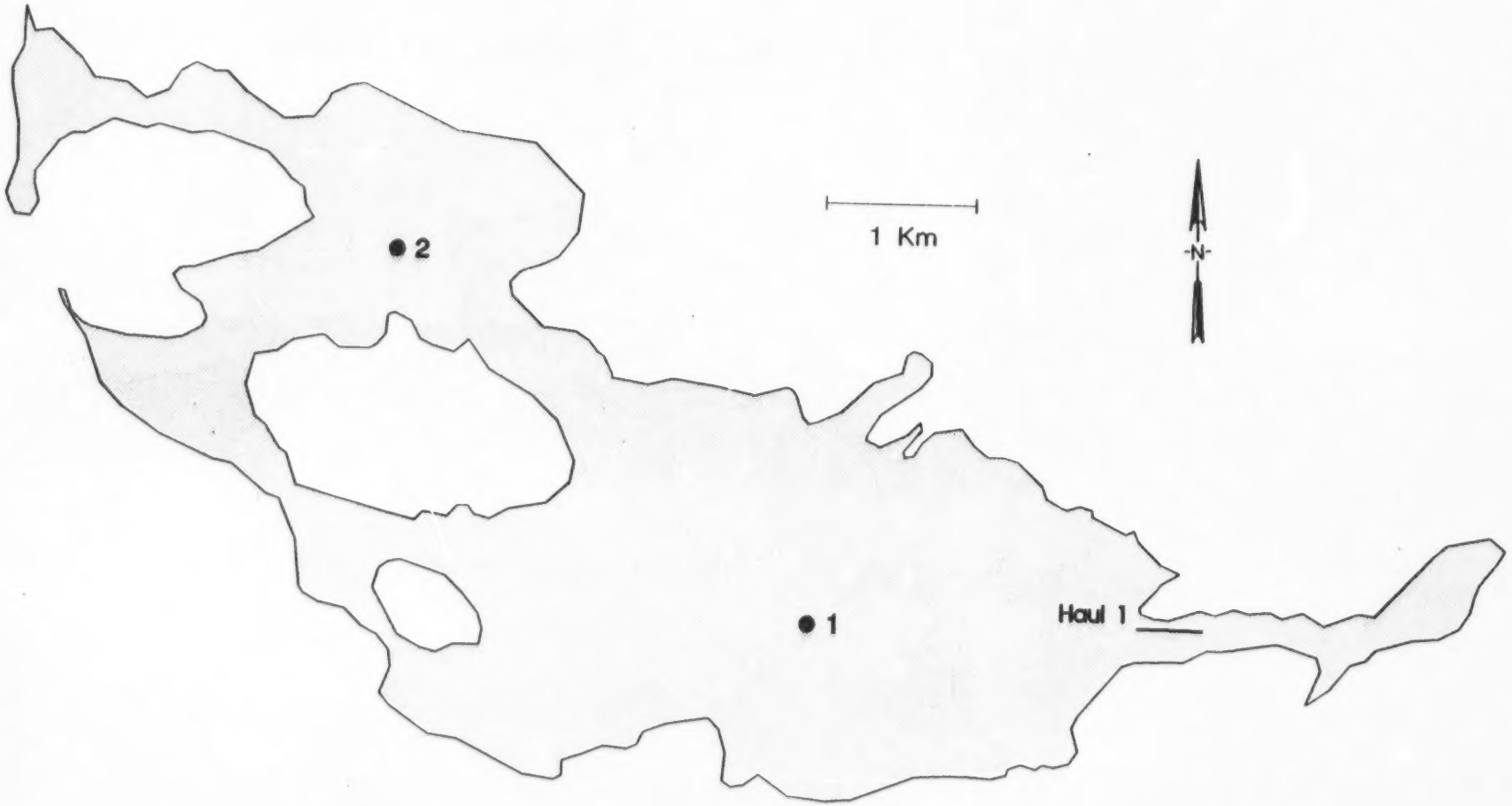

Figure 13: Locations of sampling stations on Lake Vernon